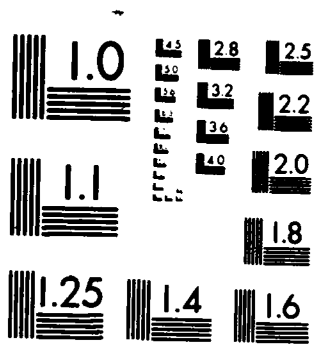
AD-A123 178 INVESTIGATION OF COLD CATHODE AND RF EXCITATION FOR LONG LIFE CO2 WAVEGUIDE LASERS(U) MARYLAND UNIV COLLEGE PARK GLENN L MARTIN INST OF TECH U HOCHULI DEC 82 1/1

UNCLASSIFIED N00014-79-C-0312 F/G 20/5 NL

END
DATE
FILMED
2-83
DTIC

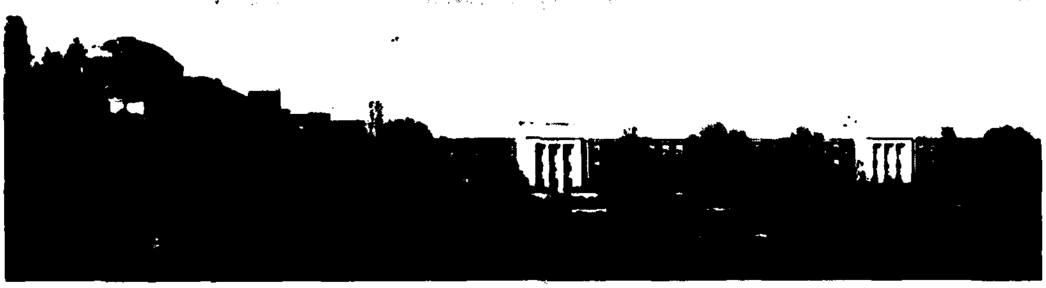


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Electrical Engineering Department
UNIVERSITY OF MARYLAND, COLLEGE PARK, MD 20742

Investigation of Cold Cathode and RF Excitation for Long Life CO_2 Waveguide Lasers

Annual Summary Report
for Contract N00014-79-C-312, P2



COLLEGE OF ENGINEERING: GLENN L. MARTIN INSTITUTE OF TECHNOLOGY

(12)

Investigation of Cold Cathode and RF Excitation

for

Long Life CO_2 Waveguide Lasers

Annual Summary Report
for Contract N00014-79-C-0312, P2

Submitted to:

Dr. V. O. Nicolai
ONR

by

U. Hochuli

December 1982

Abstract → This report describes

~~We have invented and developed~~ a Ag-Li compound cathode for the longitudinally d.c. excited, low power, CO_2 waveguide laser. Discharge tube results with this cathode produced an acceptable gas composition over a period of 10^4 hours. The sputtering rate was quite low and, most importantly, the sputtering products did adhere quite well in the form of a thin film on the closest, cooler surfaces.

A laser, using two of these cathodes, still produced 72% of its initial power output after 9200 hours of continuous service. Failure analysis indicated internal mirror damage on one of the mirrors, most likely due to improper selection of the dielectric top layer. Considerably more sputtering took place in the laser than in the discharge tube due to a laser cathode temperature that was too low.

In parallel with these efforts we have started to investigate the life potential of the transversely r.f. excited waveguide laser. Preliminary results are quite encouraging. These tests were carried out over periods close to 3000 hours and indicate that proper selection of electrode materials is quite important. We also feel that it was considerably easier to achieve laser life over this time span with r.f. excitation compared to longitudinal d.c. excitation.

Introduction

Over a period of several years we have tried to invent and perfect cold cathodes for the low power CO_2 waveguide laser with longitudinal d.c. excitation. As it turns out this is an even more difficult task than we had anticipated.

Our research has produced several cathode materials that indicate a reasonable gas composition over periods in excess of 10^4 hours in simple gas discharge test tubes. However, critical inspection reveals that most cathodes produce sputtering deposits in the form of flakes or loose flaky films. Such cathodes, if used in an actual laser, lead to a situation where an observer can claim impressive life test results of the order of 10^4 hours in the laboratory. A more critical assessment however can not escape the fact that a laser with any type of loose sputtering deposits is just not viable in the field.

Among the roughly one hundred different cathode material-gas mixture compositions tested so far in discharge tubes we have found a Ag-Li compount cathode to be our best solution with the He CO_2 CO Xe gas mixture. Gas discharge tube and laser results with these cathodes will be discussed in the following paragraphs.

Realizing that our approach, the perfection of cold cathodes for the longitudinally d.c. excited laser, was not progressing as fast as we had hoped we decided to investigate transverse r.f. laser excitation. The necessary r.f. oscillators, amplifiers as well as the suitable laser structures were built. The preliminary results of these r.f. tests will also be discussed.

Discharge Tube Results

CO and CO_2 contents, measured by infrared absorption spectroscopy, are shown in Figure 1. These results indicate that the Ag-Li compound cathode used may yield laser life of the order of 10^4 hours. This result alone does not qualify it as an outstanding cathode. The most pleasant and surprising aspects are its low sputtering rate and the absence of loose sputtering products outside of the cathode cavity. Figure A-2 shows the discharge tube after 20,000 hours of continuous operation. Its glass envelope reveals only a light film formed from sputtering products, with good wall adhesion and the sputter-shield is quite clean. Figure A-3 exhibits the cathode assembly and the anode of the disected discharge tube. The deposits visible on the anode sheet indicate that material transport from cathode to anode had taken place. Figure A-4 shows the cathode assembly, cut in half along the cathode axis. The cathode cavity itself is covered by a burr and can not be seen. The interesting detail, clearly visible here, is the erosion that took place in the throat of the sputtershield. The throat, originally a cylindrical hole, now shows the standing wave pattern caused by plasma oscillations. Regrinding to remove the burr resulted in a cut that is not parallel anymore with the cathode axis but opened the cavity for inspection as shown in Figure A-5. The original shape of the cavity bottom duplicated the drill point used to machine it. The bottom is now well rounded and the removed material has relocated and filled-in the top edge of the cavity. This process apparently took place without forming loose sputtering products.

Auger spectroscopy of the anode revealed the presence of Ag, Li, C and Al_2O_3. The latter is again a confirmation of the sputtershield throat erosion mentioned before. The sputtershield was formed from Diamonite P-3142-1 material which consists of 95 to 97% Al_2O_3 + binder with a trace of Cr_2O_3, responsible for its pink color.

D.C. excited Laser

Two of these structures, shown in Figure A-1 (Crossection shown in Figure 2) were assembled and put on life tests. The first laser had one Pt anode at each bore end and a common 4mA Ag-Li compound cathode in the center. Life test results, shown in Figure 3, indicate a disappointingly low life of 1900 hours for the first run. The laser was then evacuated and refilled for a second test. The initial power output for the second test was slightly higher than for the first test, an indication that so far no serious mirror degradation had taken place. Laser life turned out to be even shorter, only 450 hours. We discovered later that the laser envelope had developed a vacuum leak at one of its seals. Inspection of the cathode indicated fairly heavy erosion. In one place the cathode spot had produced a hole clear through the cathode wall out to the sputtershield. Unfortunately we do not know if the cathode current of 4mA was excessive or if the presence of air was responsible for this result. We felt that this test had failed and no further analysis was made on this laser.

The second laser used three similar Ag-Li compound electrodes: one at each bore end served as a 2mA cathode and one functioned as the common 4mA anode at the center. Test results for this laser are shown in Figure 4 and indicate that this laser still produced

72% of its original power output after 9200 hours of continuous operation. This is quite an impressive result but only a necessary and not sufficient condition for a viable laser. The "acid test" requires the absence of all loose sputtering products inside of the laser. Before opening the laser it was first carefully pumped down and refilled. The new gas mixture resulted only in an insignificant power increase over the old one. Evacuation with the vacion pump for two days at 100°C followed by a refill did not increase the power either. This is usually an indication that mirror damage has occurred.

The laser was then opened and carefully inspected. We found one loose, black particle of roughly 0.03mm in diameter in one of the 0.313" holes in the BeO block that accepts the cathode assembly. Both cathode sputtershields had black front surfaces and even the anode shield showed some black deposits. Figure A-3 allows comparison of these three electrode shields with the one from the discharge tube. These results clearly show that the laser cathodes behaved quite differently from the one in the discharge tube. The most likely explanation is the difference in the cathode temperatures. Figure 5, representative of the discharge tube cathode, shows a cathode temperature of 215°C for a cathode current of 3mA. Temperature measurements of the similar cathode in the well cooled BeO body of the laser are shown in Figure 6 and reveal a cathode temperature of only 63°C.

Mirror damage, as seen by the eye and under the microscope, were quite different for the two mirrors. The totally reflecting mirror consisted of a ZnSe substrate coated with Ag, ThF_4 and had

a top layer of ZnSe. The 94% reflective mirror, again on a ZnSe substrate, had alternating layers of ThF_4 and ZnS with ZnS as the top layer. Mirror damage, as seen by the eye and under the microscope was minimal for the 100% mirror while the central spot of the 94% mirror was much better visible. This difference became far more pronounced after both mirrors had been exposed for a few days to atmospheric conditions. The 100% mirror did not seem to change, while the 94% mirror,which always looked slightly darker than the yellower 100% mirror,turned grayer and the central spot started to look like the surface of a crystalizing liquid as shown in Figure A-6. Auger analysis, performed for us by NSA, shows ZnSe, Ag, Li and C on the 100% mirror and ZnS, Ag,C and no Li on the 94% mirror. This confirms our previous analysis of the top coatings performed with x-ray fluorescent spectroscopy. The Ag and Li deposits are clearly the result of transported cathode material. For a symmetrical laser structure we would expect similar amounts of cathode material on both mirrors. The absence of Li on one mirror can perhaps be explained by the assumption that Li on ZnS had formed a sufficiently volatile compound for removal by the previous vacuum bake-out at 100°C.

This result clearly shows that the proper selection of the dielectric top layer of the mirror coating can be quite important. In our situation it turned out that the combination of a Ag-Li cathode with the dielectric ZnS mirror film was a poor one and could easily have been avoided.

Conclusions

It is proving to be rather difficult to obtain field performance in excess of 10^4 hours for the longitudinally d.c. excited, low power CO_2 waveguide laser. Our present solution still requires additional work, namely: the mirror surfaces have to be properly selected, the cathode temperature must be raised and the laser should be subjected to repetitive on-off cycle testing. It should also be pointed out that our lasers were not frequency controlled to yield continuously maximum power output. The lasers drifted back and forth over part of their signatures resulting in a power output that averaged roughly one half of the maximum power.

We also believe that it will not be a trivial matter to scale this technology to higher power levels without additional research and development.

RF Excitation

This type of excitation, in contrast to d.c. excitation with cold cathodes, does not require energetic ion impact on an electrode surface to provide electron emission. For this reason alone one would expect little if any sputtering in devices so excited. In order to test the laser performance with r.f. excitation we have built the necessary oscillators, r.f. amplifiers and laser structures. Figures B-1 to B-4 show these laser structures and their individual parts before, during and after final assembly. The ceramic waveguide is fabricated from BeO and no epoxy resin is used anywhere. Figure B-1 shows the waveguide crossection, essentially a BeO channel in form of an inverted U, resting on a Cu block. The transverse r.f. excitation is capacitively coupled through the thin 0.015" BeO top into the gas filled, 1.5mm x 1.5mm, crossection of the waveguide. The Cu block at the bottom serves as the other electrode as well as the water cooled heat sink.

In order to quickly study and determine the performance of several different electrode materials we have milled a central channel through the copper block, inlaid it with sections of Cu, alternating with Ni, Au, Pt, Ag and 304 type of stainless steel and repolished the surface. The power output of this laser vs time is shown in Figure 7. It indicates a power decrease from 2.6 to 2.5W over the first 840 hours. The laser was turned on and off repeatedly during the 840 to 1000 hour time interval in order that work could be performed on the RF matching networks. RF power input varied between 20 and 50 watts and it is conceivable that this overloaded the laser. In any case the laser

never fully recovered and its power stayed between 2 and 1.8 watts between 1000 and 3000 hours respectively. Gas analysis at 3200 hours indicated CO_2 depletion and a 2 hour pump down and refill restored the laser power outpus to its initial value. Thus no serious damage had occurred over this period of time.

The laser was then disassembled and a visual inspection of Figure B-5 shows that considerable sputtering had taken place on some electrode surfaces. Ordering the electrode materials according to the visual sputtering deposits we fin(Pt to have the least, followed by stainless steel, Au, Cu, A(and Ni. Ni was by far the worst of the tested materials and its sputtering was so bad that even the BeO channel was covered with black NiO. These results were obtained by using a gas mixture containing He, Co_2, CO and Xe. The electrodes were then repolished, the laser structure cleaned, assembled and refilled with a He-CO_2-N_2-Xe gas mixture. The performance of this laser is shown in Figure 8. Since no effort was made to optimize the gas mixture and in view of the particular test conditions it would be premature to compare the initial output and the power drop from 2W to 1.3W with the previous result. Refilling the laser restored its initial power output. The structure was then dismantled and the inlaid copper block examined for sputtering. To the naked eye the appearance was practically identical to the previous result shown in Figure B-5.

From these two tests it seems that Pt is the best electrode material choice for both, CO or N_2 containing gas mixtures. It should be carefully pointed out that this choice is the result of

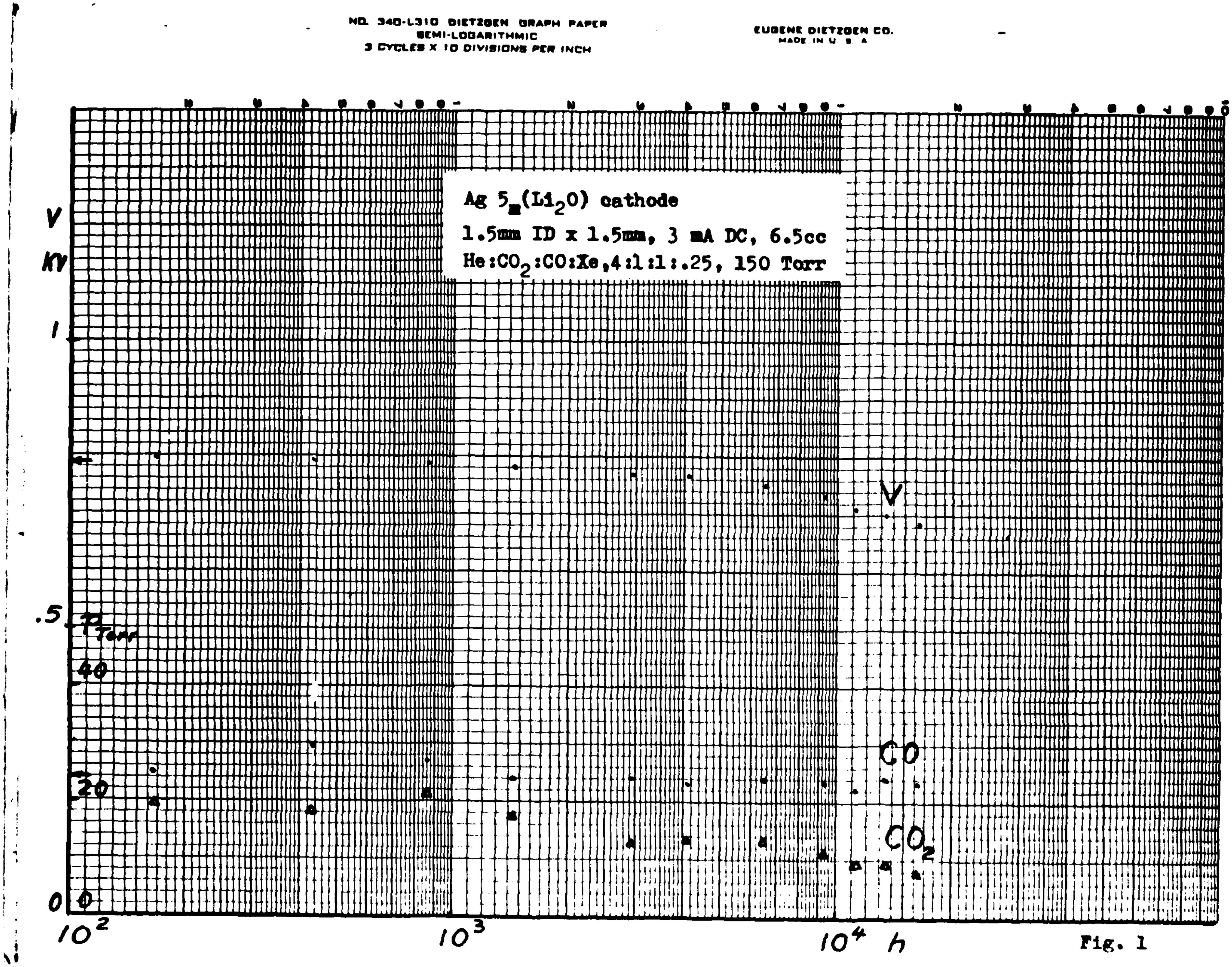
a visual inspection after test runs that lasted less than 3000 hours and not the result of a 10^4 hour life test. In such prolonged life tests there always exists the possibility that a small amount of electrode material may be transported in a gaseous phase and end up damaging the mirror surfaces. A similar possibility exists if the laser is periodically turned on and off. Each time the laser is turned on a small shock wave is produced and we simply do not know how Pt or any other electrode material behaves under these conditions.

Conclusions

Preliminary results with r.f. excitation indicate that the proper choice of materials is still a very important parameter. We also have to admit that it was considerably easier to achieve about 3000 hours of laser life with this type of excitation than with the cold cathodes. RF excitation results were also quite similar with both, CO or N_2 containing laser gas mixtures, a situation we were never able to achieve with cold cathodes.

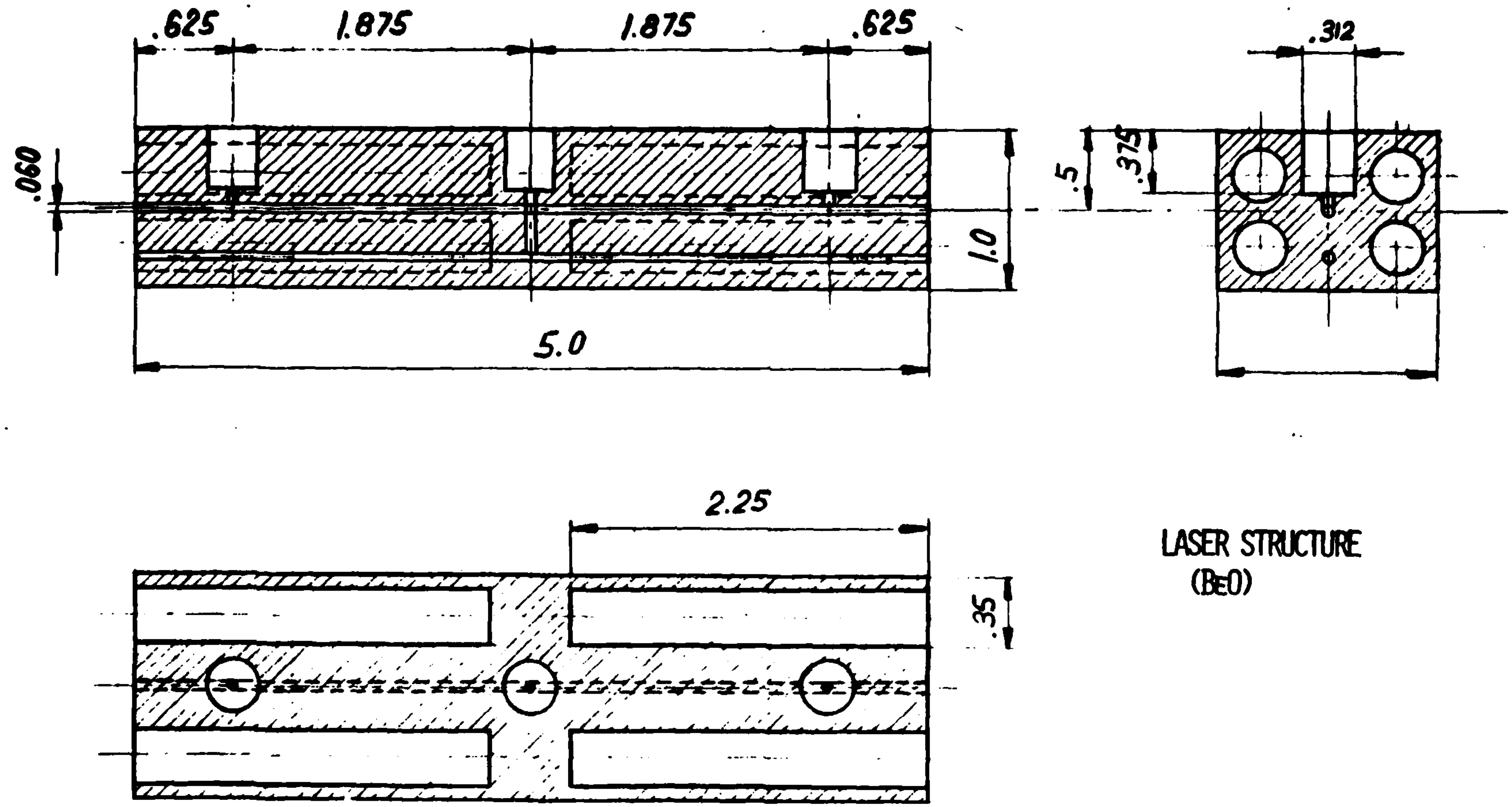
Acknowledgement

The research, described in this report, was sponsored by the Navy and the Air Force under contracts N00014-79-C-312, P2 and AFOSR-82-0058 respectively.



NO. 340-L310 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.
Ag 5m(Li2O) cathode
1.5mm ID x 1.5mm, 3 mA DC, 6.5cc
He:CO2:CO:Xe,4:1:1:.25, 150 Torr
V
KV
1
.5
P Torr
40
20
0
0
10^2
10^3
10^4
h
V
CO
CO2

Fig. 1



LASER STRUCTURE
(BeO)

Fig. 2

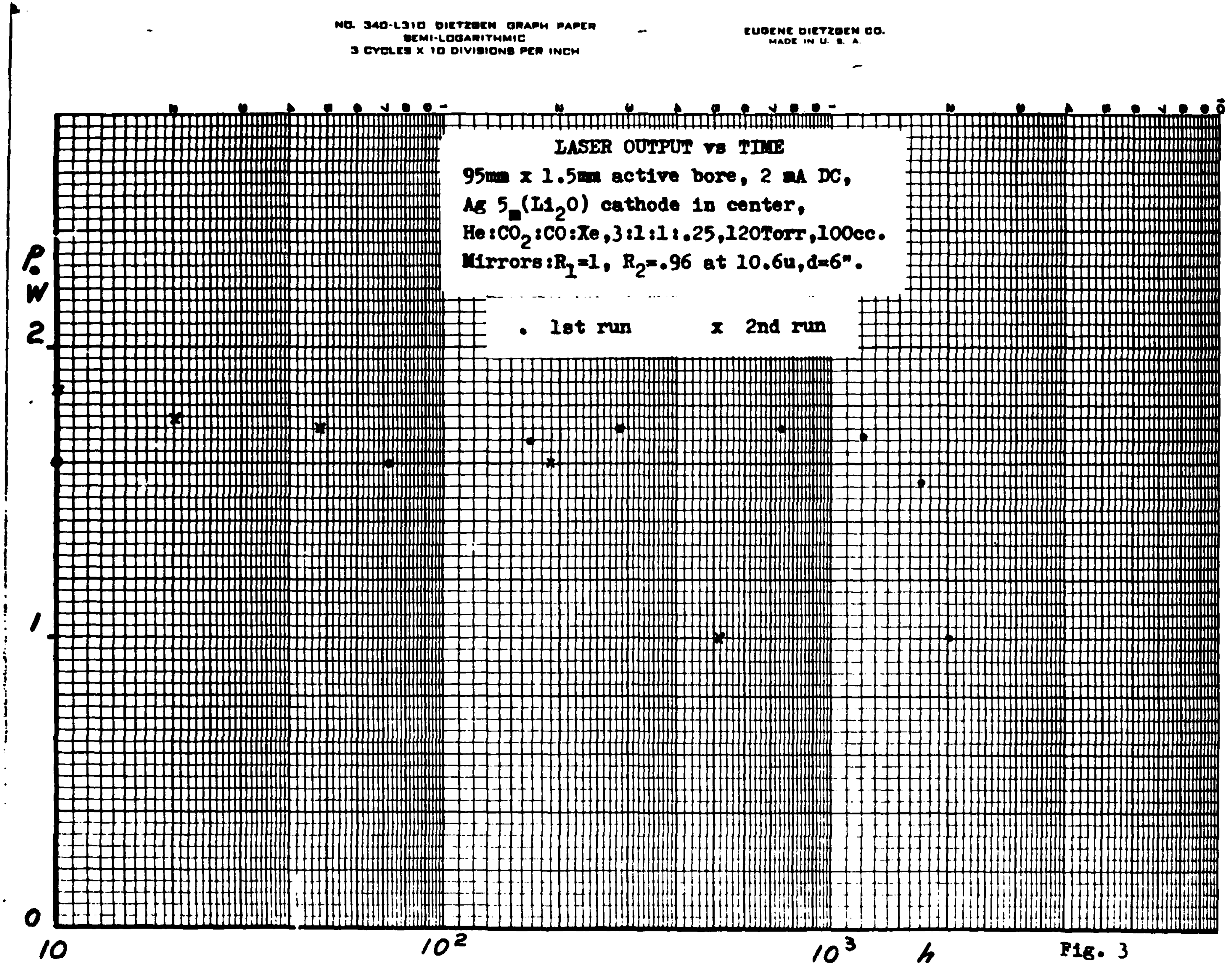

NO. 340-L310 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.
LASER OUTPUT vs TIME
95mm x 1.5mm active bore, 2 mA DC,
Ag 5m(Li2O) cathode in center,
He:CO2:CO:Xe,3:1:1:.25,120Torr,100cc.
Mirrors:R1=1, R2=.96 at 10.6u,d=6".
. 1st run
x 2nd run
P. W
2
1
0
10
10^2
10^3
h

Fig. 3

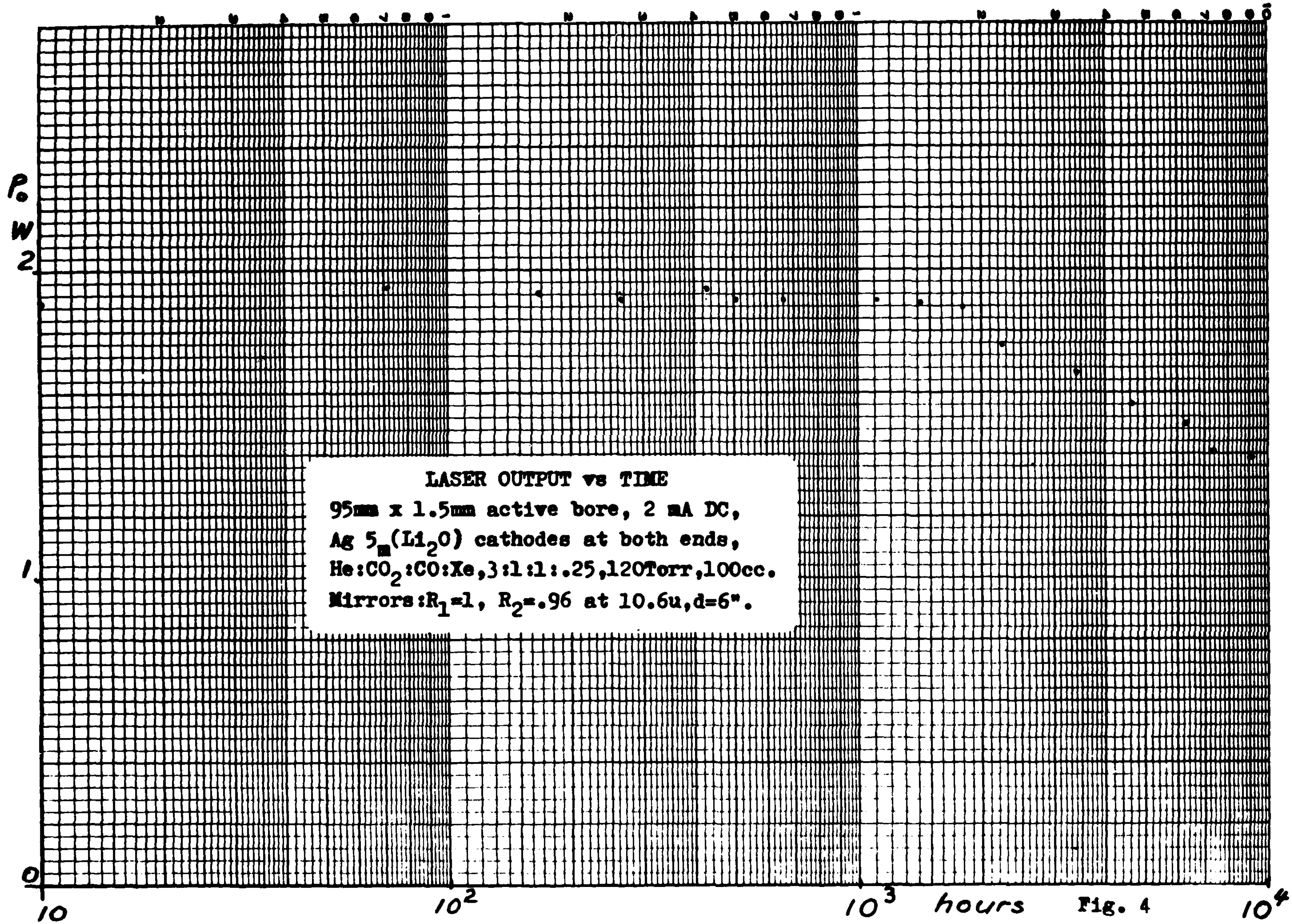

LASER OUTPUT vs TIME
95mm x 1.5mm active bore, 2 mA DC,
Ag $5_m(Li_2O)$ cathodes at both ends,
He:CO_2:CO:Xe,3:1:1:.25,120Torr,100cc.
Mirrors:R_1=1, R_2=.96 at 10.6u,d=6".
P_o
W
2
1
0
10
10^2
10^3
hours
10^4

Fig. 4

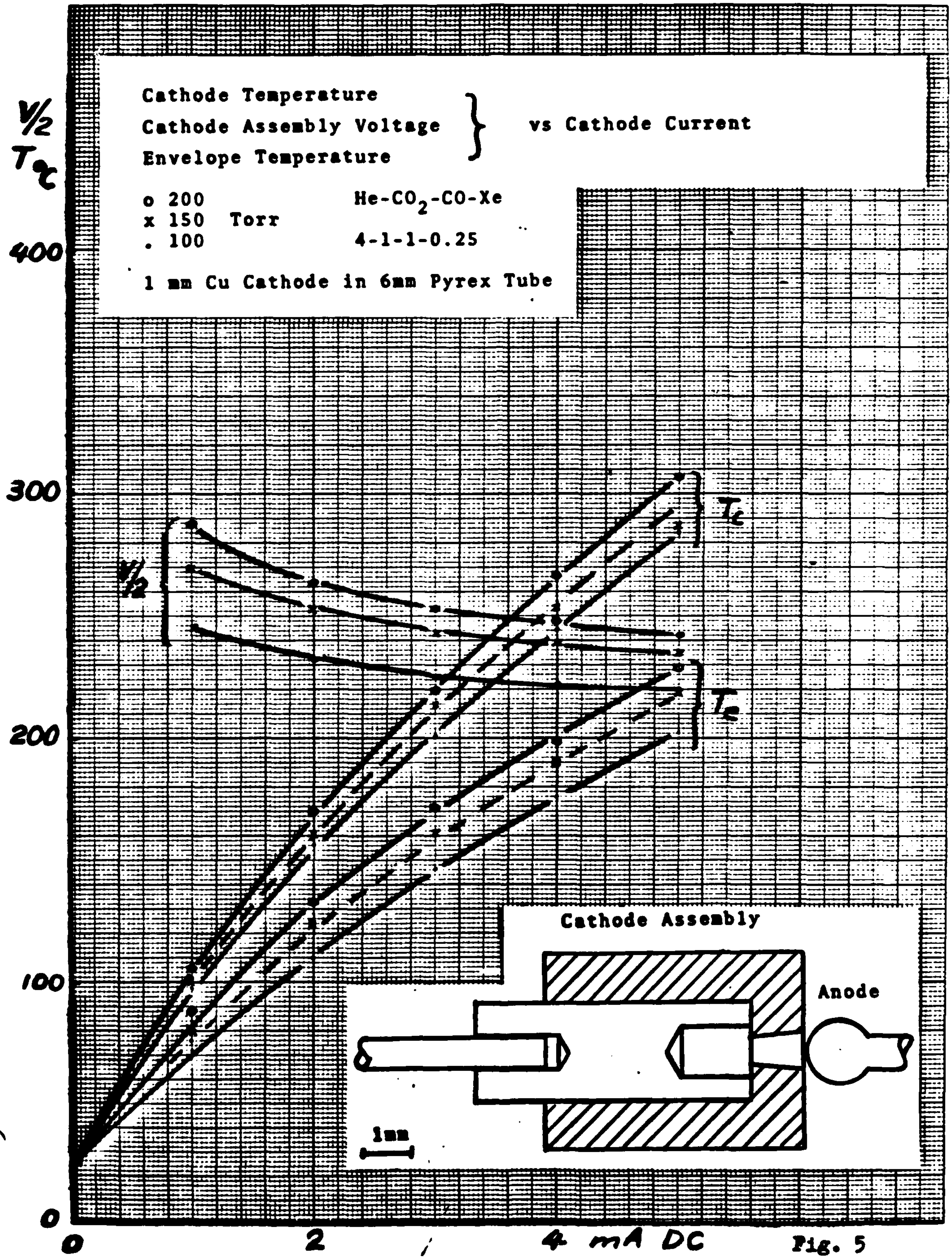
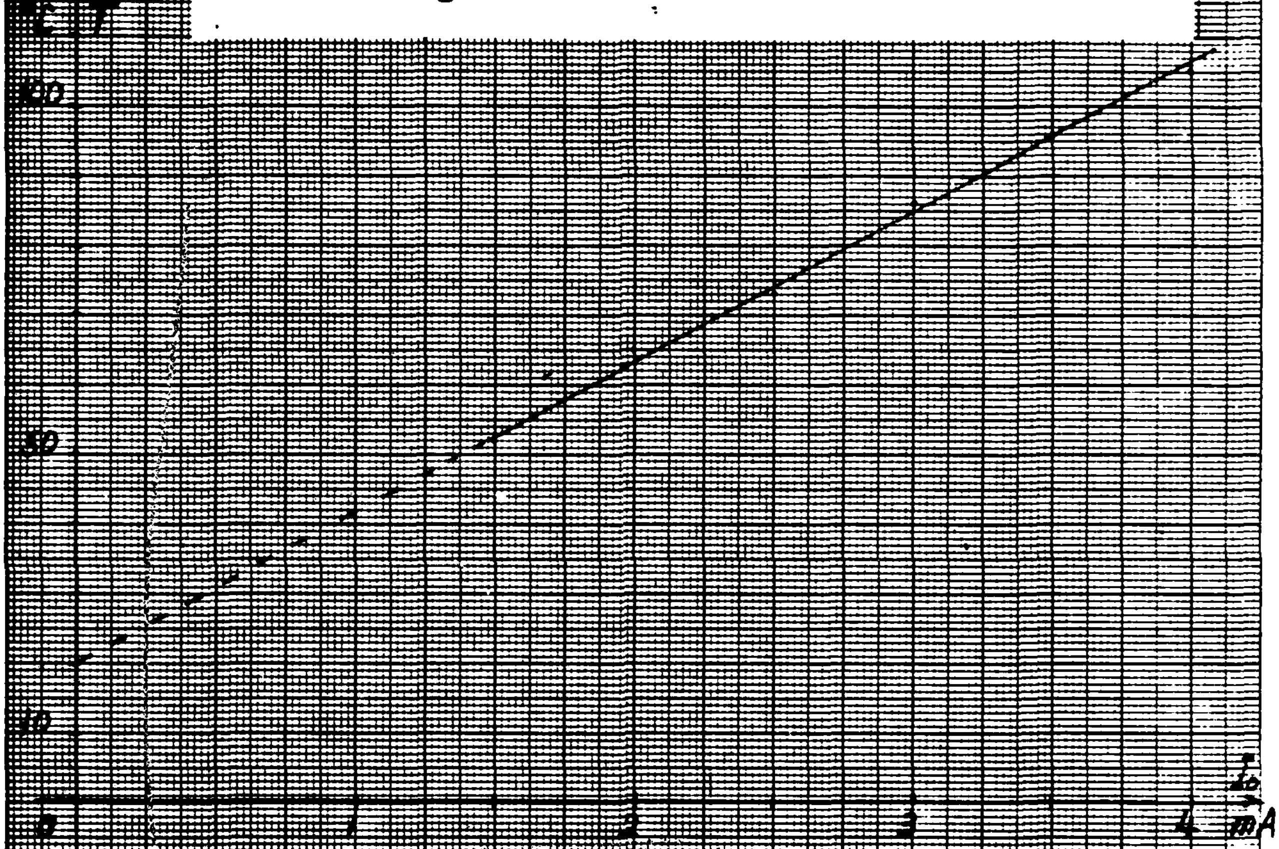

Cathode Temperature
Cathode Assembly Voltage
Envelope Temperature
vs Cathode Current
o 200
x 150 Torr
. 100
He-CO2-CO-Xe
4-1-1-0.25
1 mm Cu Cathode in 6mm Pyrex Tube
V/2
Tc
Te
400
300
200
100
0
0
2
4 mA DC
Cathode Assembly
Anode
1mm

Fig. 5

CATHODE TEMPERATURE vs DISCHARGE CURRENT

Copper cathode

$He:CO_2:CO:Xe$, 3:1:1:.25, 30 to 160 Torr



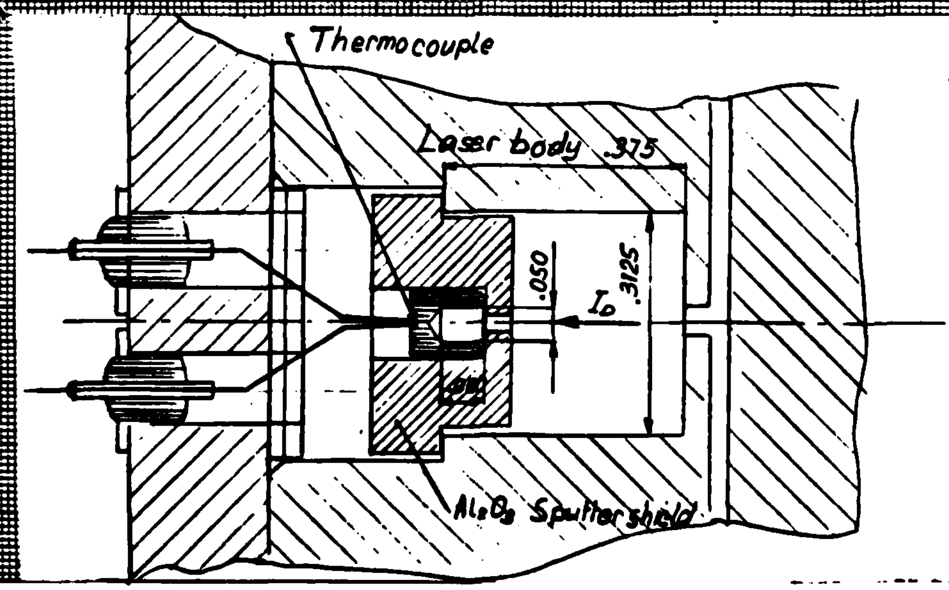


Fig. 6

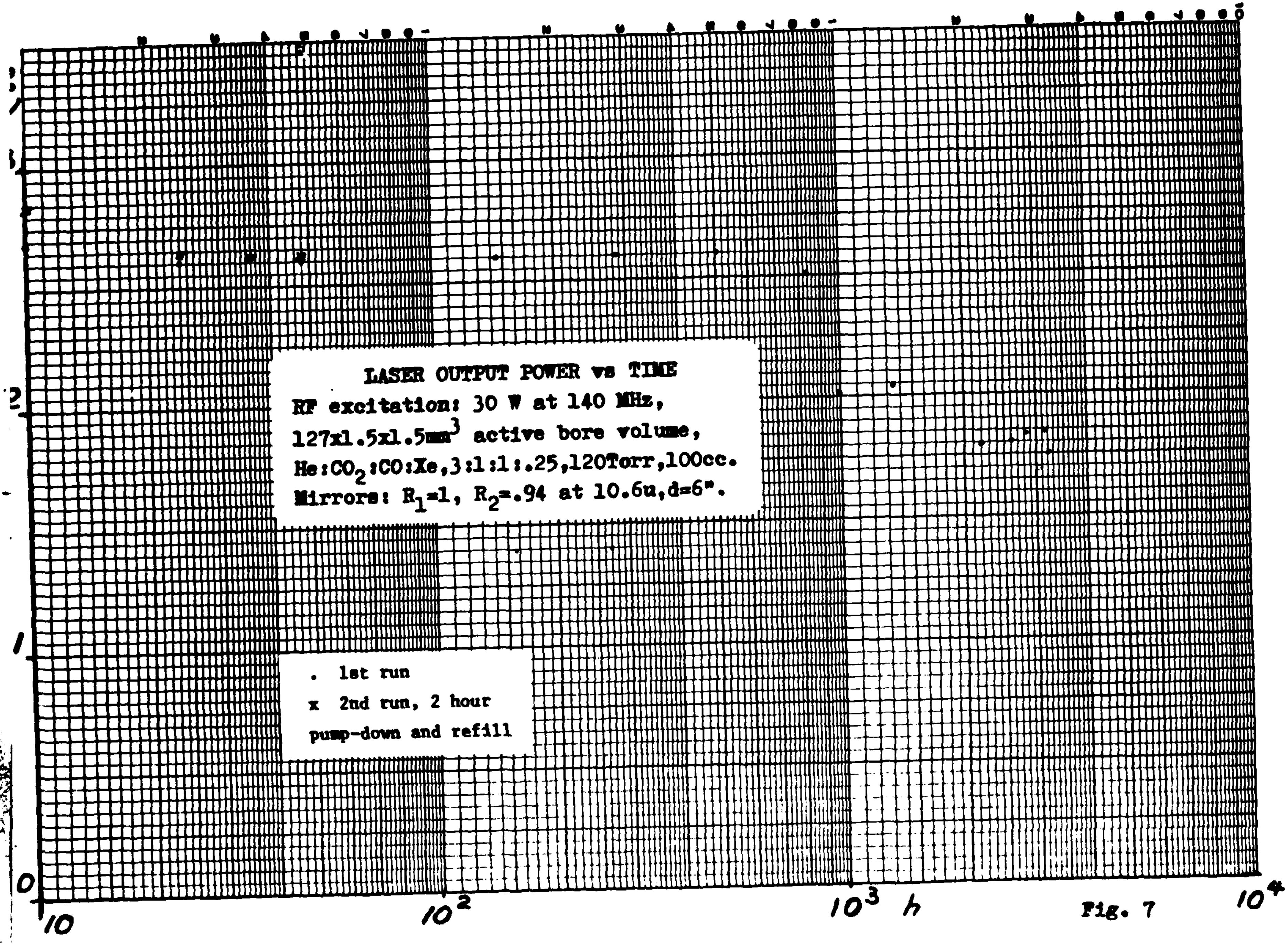

LASER OUTPUT POWER vs TIME
RF excitation: 30 W at 140 MHz,
127x1.5x1.5mm³ active bore volume,
He:CO₂:CO:Xe,3:1:1:.25,120Torr,100cc.
Mirrors: R₁=1, R₂=.94 at 10.6u,d=6".
. 1st run
x 2nd run, 2 hour
pump-down and refill
0
1
2
10
10²
10³ h
10⁴

Fig. 7

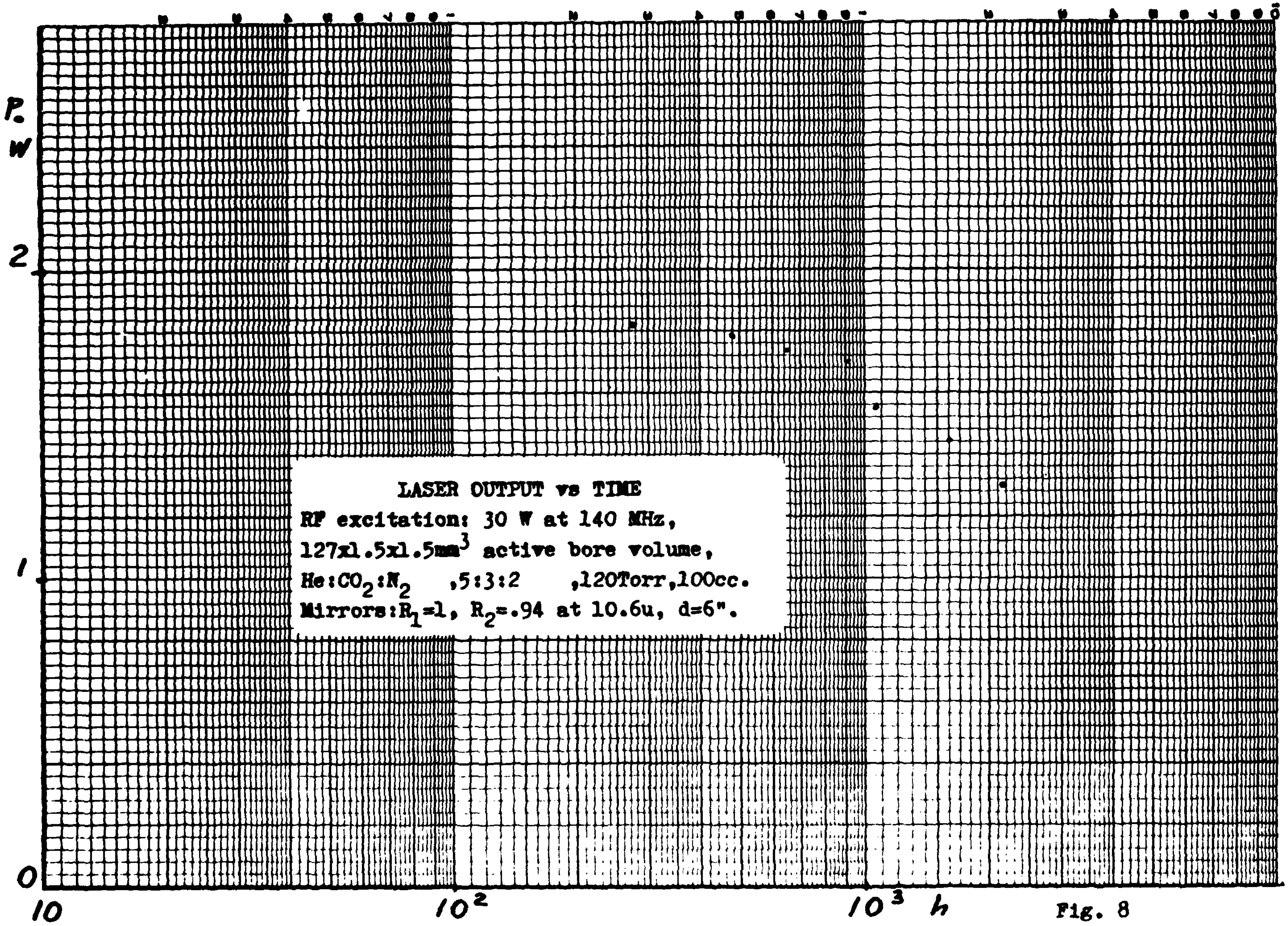

P. W
2
1
0
10
10^2
10^3 h
LASER OUTPUT vs TIME
RF excitation: 30 W at 140 MHz,
$127x1.5x1.5mm^3$ active bore volume,
$He:CO_2:N_2$,5:3:2 ,120Torr,100cc.
Mirrors: R_1=1, R_2=.94 at 10.6u, d=6".

Fig. 8

FAILURE ANALYSIS

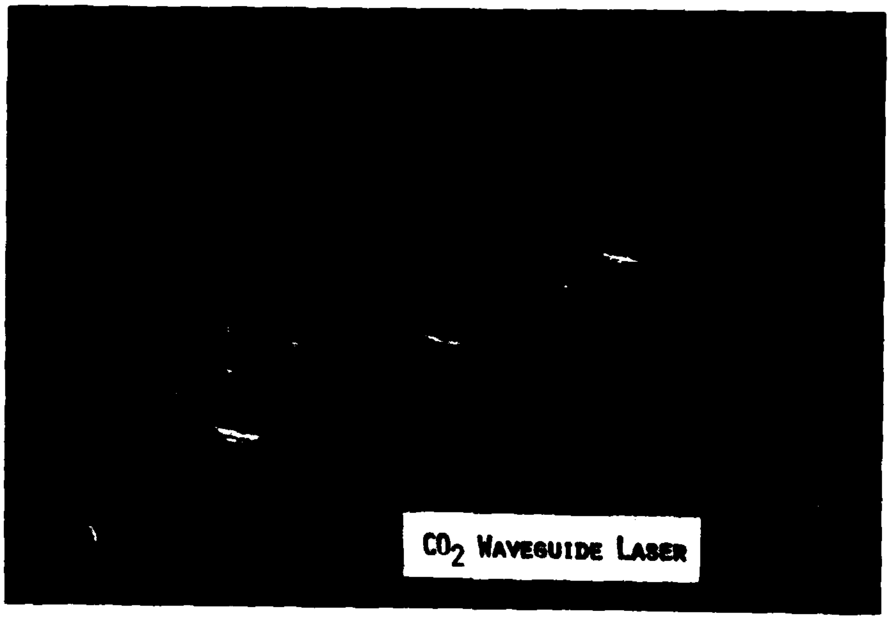


Fig. A-1

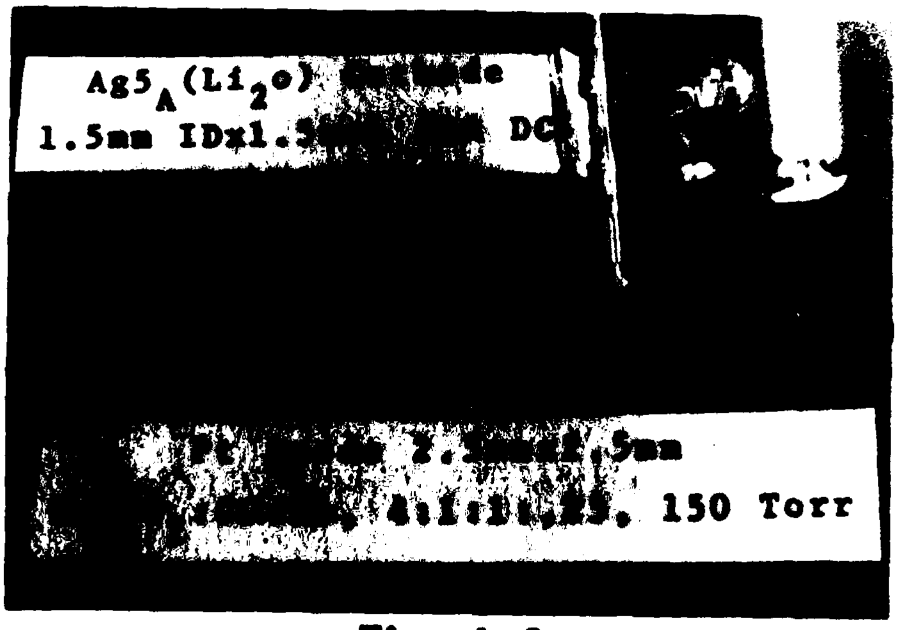


Fig. A-2

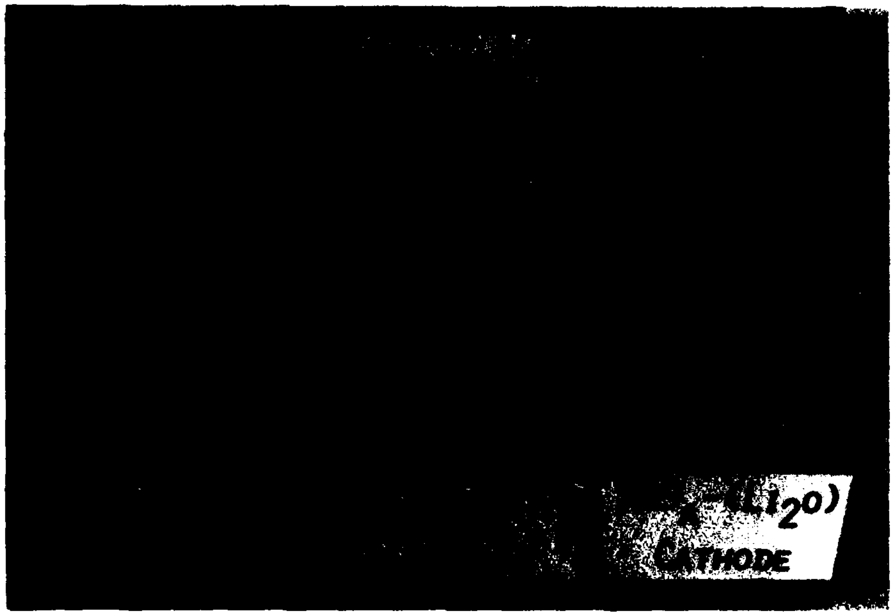


Fig. A-3

Fig. A-4

Fig. A-5

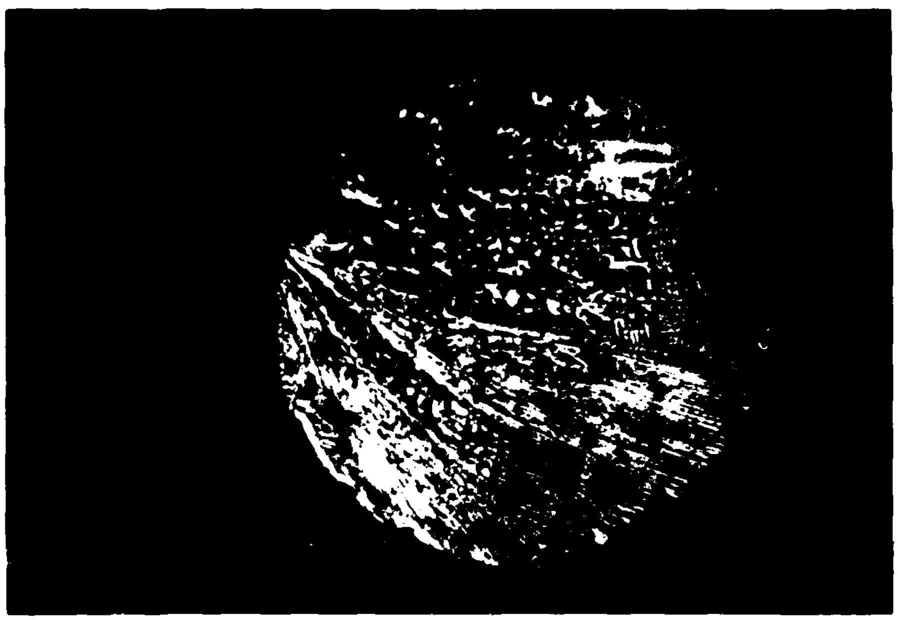


Fig. A-6

RF EXCITED

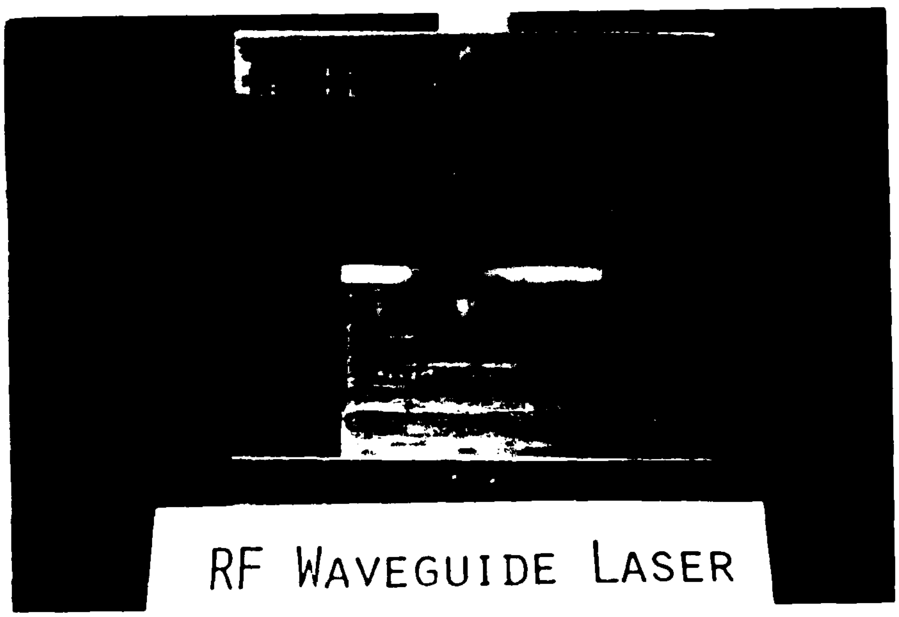


Fig B-1

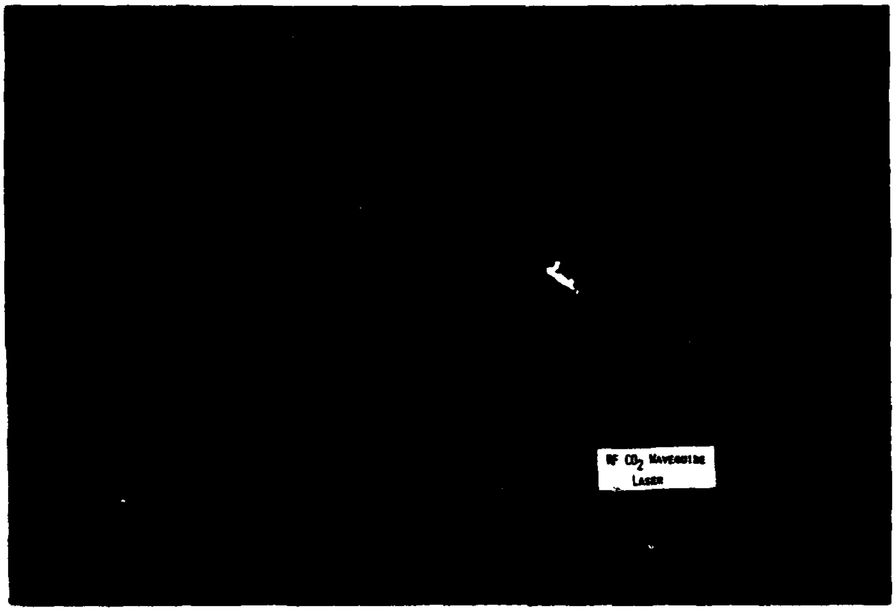


Fig B-2

Fig B-3

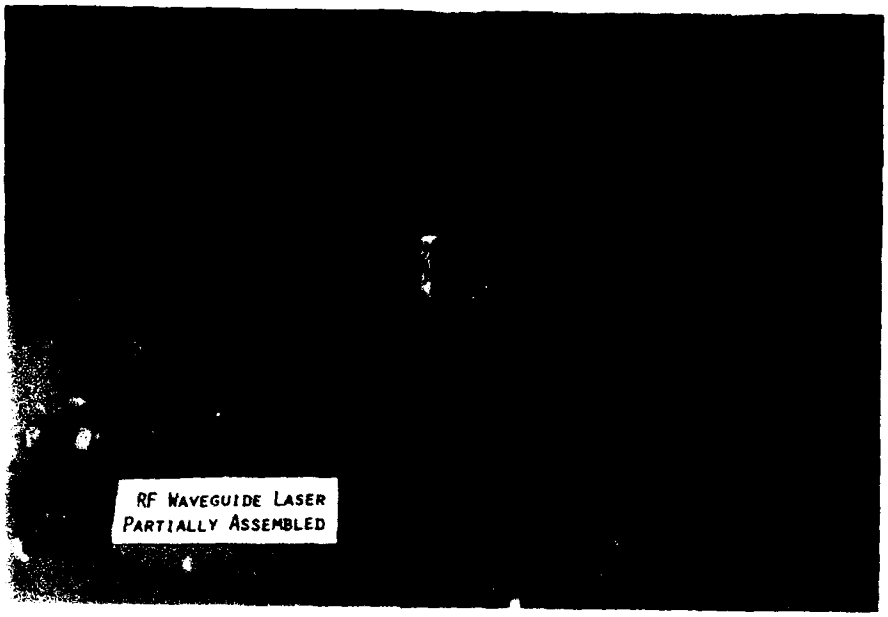

RF WAVEGUIDE LASER
PARTIALLY ASSEMBLED

Fig B-4

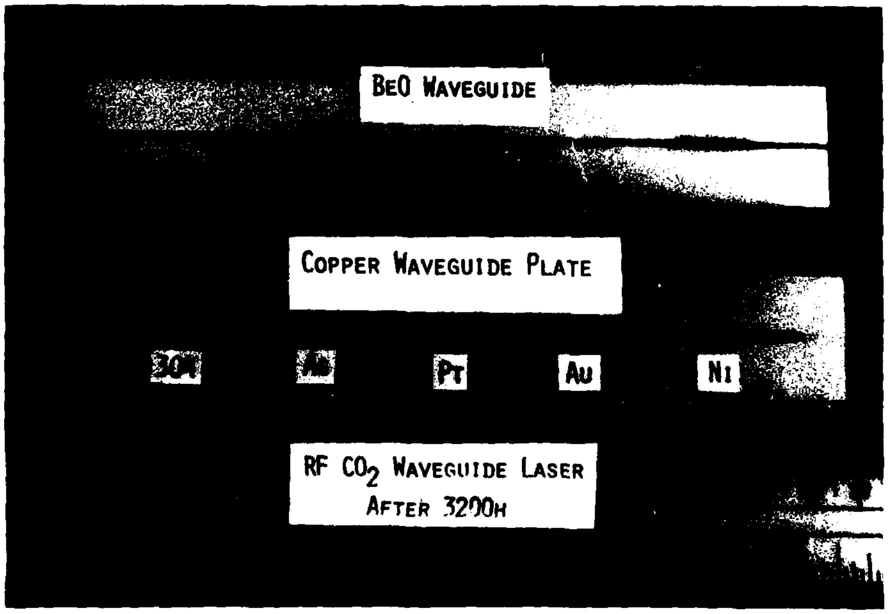

BeO WAVEGUIDE
COPPER WAVEGUIDE PLATE
Pt
Au
Ni
RF CO_2 WAVEGUIDE LASER
AFTER 3200H

Fig B-5

LME

-83